5629 Au-Pt Thermocouple

User Manual

Hart Scientific

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WARNING

READ SECTION ENTITLED

Au/Pt TC Care and Handling Guidelines

before removing the Au/Pt THERMOCOUPLE from the case.

Incorrect handling can damage the Au/PT THERMOCOUPLE and void the warranty.

WARNING

KEEP THE SHIPPING CONTAINER

in case it is necessary to ship the Au/PT THERMOCOUPLE.

Incorrect packaging of the Au/Pt THERMOCOUPLE for shipment can cause irreparable damage.

Table of Contents

1 Introduction

1.1 General

The Hart Model 5629 standard gold/platinum thermocouple (Au/Pt TC) is manufactured at Hart according to the technique described in a National Institute of Standards and Technology (NIST) published paper [1] by using pure (99.999+%) gold wire and pure (99.999+%) platinum wire. The Model 5629 provides a reference thermometer with high accuracy up to 1000°C.

Both investigations undertaken by McLaren and Murdock at the National Research Council of Canada (NRC) [2], and by Burns at NIST [1] demonstrated that the gold/platinum thermocouple has excellent stability and wonderful thermoelectric homogeneity. The Au/Pt TC is greatly superior in performance to a type S thermocouple, which defines the IPTS-68 from 630.74°C to 1064.43°C. The best expanded uncertainty (k=2) you can obtain from a type S thermocouple is about 0.2°C. You can expect, however, an expanded uncertainty of 0.01°C (or even 0.005°C) from a Au/Pt TC [1]. One of two thermoelements of a type S thermocouple is an alloy of 90% Pt and 10% Rh. Many of the problems encountered with a type S thermocouple are caused by the alloy thermoelement. Preferential oxidation of rhodium above 500°C in the alloy thermoelement will lead to depletion of the dissolved rhodium in the alloy arm, and hence, to a reduced thermal emf. This depletion increases the thermoelectric inhomogeneity. Since the two thermoelements of the Au/Pt TC are pure metals, there are no such problems. Gold and platinum are the most stable metals in the air atmosphere up to 1000°C. Thus the combination of gold and platinum provides an ideal reference thermometer with high accuracy up to 1000°C.

The achievable stability and accuracy of a Au/Pt TC can be close to that of a high temperature standard platinum resistance thermometer (HTSPRT), which defines the ITS-90 up to 961.78°C. The HTSPRT is an extremely delicate instrument and requires very sophisticated personnel and equipment to achieve accurate results. On the other hand, the Au/Pt TC is much easier to use and only requires a 7 1/2 or better digital multi-meter to achieve an accuracy of 0.01°C up to 1000°C. The Au/Pt TC is an excellent, practical reference standard thermometer up to 1000°C.

1.2 Application

The Hart 5629 standard gold/platinum thermocouple is a high-accuracy temperature standard as well as a practical thermometer with high accuracy up to 1000 °C. The Hart 5629 Au/Pt TC can be used to transfer the ITS-90 from a standard laboratory to a customer’s laboratory where an expanded uncertainty of ± 0.02°C (k=2) is acceptable. This thermocouple is particularly good at high temperatures because it is easier to handle than HTSPRTs. This theromocouple is also less susceptible to damage from metal ion contamination and mechanical shock. Additionally, thermocouples do not require pre-heating for high-temperature use.

1.3 Calibration

Due to the metal purity of the Au/Pt TC, an uncalibrated 5629 achieves accuracy within ± 0.05°C using the EMF-to-temperature function developed by NIST. However, in order for any instrument to be used as a standard it must be calibrated. Each delivered thermocouple includes a fixed-point calibration at the freezing points of Zinc, Aluminum, and Silver. The calibration is traceable to NIST. From the calibration, two deviation coefficients are derived which, in conjunction with the NIST function, provide maximum accuracy. More detailed information is contained in Section 6.

2 Specifications and Warranty

2.1 Specifications

Temperature Range	0° to 1000°C
Thermocouple Materials	99.999% pure gold, 99.999% pure platinum
Sheath Materials	Measurement junction - fused quartz Reference junction - stainless steel
Calibration	Freeze points of Zinc, Aluminum, and Silver included
Calibration Uncertainty	±0.020°C (expanded uncertainty [k=2] over entire range)
Stability	better than ±0.020°C
Measurement Junctions Dimensions	7.0 mm diameter x 600 mm length
Reference Junction Dimensions	5.56 mm diameter x 229 mm length
EMF vs. Temperature Function	NIST equation (Coefficient values included with certificate)
Accuracy	Accuracy will vary according to usage techniques and conditions. Under reasonably good conditions uncertainties of ±0.02°C can be expected

2.2 Construction

The construction of the Model 5629 thermocouple is shown in Figures 1 and 2. The design is based on the NIST and NRC guidelines. Additionally, a fused quartz sheath is attached to protect the thermocouple; and a stainless steel sheath is used for the reference junction. Gold wire and platinum wire both of 99.999+% purity (0.5 mm diameter) are mounted in twin-bore alumina insulat-

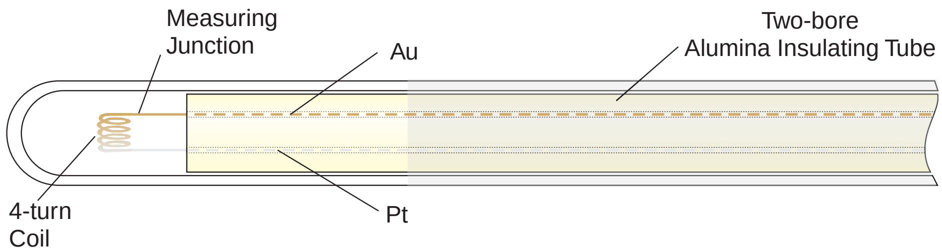

Figure 1 *Detailed Construction of Measuring Junction*

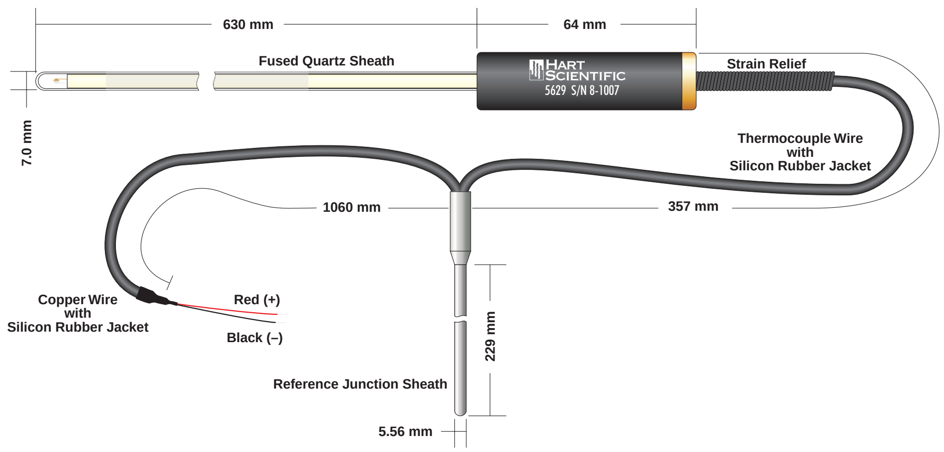

Figure 2 *Construction and Standard Dimensions*

ing tube (1.6 mm bores, 4.7 mm in diameter and 610 mm long). A 4-turn coil, 1 mm in diameter, of 0.2 mm platinum wire connects the gold and platinum thermocouple wires at the measuring junction. See Figure 1 for details. The wires emerging from the alumina insulating tube are insulated with flexible fiberglass tubing. The fiberglass tubing is joined to the alumina tube with heat-shrink tubing. A small bar-type clamp is used to softly compress the insulation against the thermocouple wires. A pair of polyvinyl-insulated copper wires is soldered to the gold and platinum wires to form the reference junction. A stainless steel sheath is used to house the reference junction. Silicone rubber sleevings are used to cover the thermocouple wires and the insulated copper wires. See Figure 2 for details.

2.3 Electrical Circuit

The Au/Pt thermocouple is provided with a terminal box handle. The eight-foot cable has two fiberglass-coated wires enclosed in a silicon rubber jacket with a stainless steel spring strain relief. The bare wire termination allows the thermocouple to be connected to any nanovoltmeter or other read-out device.

2.4 Warranty

The 5629 gold/platinum thermocouple is covered by a 90-day warranty that takes effect 10 days after the product is shipped. The manufacturer will provide parts and labor without charge for repair or replacement of the instrument due to defects in material or workmanship. The warranty will not apply if the product has not been used according to the instruction manual or has been tampered with by the user. For service or assistance, please contact the manufacturer.

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3 Installation

3.1 Environmental Issues

Ideally temperature calibration equipment should be used in a calibration laboratory or other facility specifically designed for this purpose. Environmental requirements include:

- Stable temperature and humidity.
- Clean, draft-free area.
- Low noise level: low radio frequency, magnetic or electrical interference.
- Low vibration levels.

3.2 Mounting

Most often temperature standards, primary and secondary, are used to calibrate other temperature-sensitive equipment. The Au/Pt TC must be mounted carefully to avoid any damage to the sheath or sensor. If the heat source does not have a designated lid or other support for the Au/Pt TC, clamps should be used to ensure the TC is supported properly.

3.3 Lead Wire Identification

The 5629 Au/Pt TC is equipped with two lead-wires encased in a polyvinyl protective covering. Flexible fiberglass sheathing protects the lead-wires. The positive thermoelement is sheathed in red and the negative thermoelement is sheathed in black. (See Figure 2)

4 Au/Pt TC Care and Handling Guidelines

CAUTION
READ BEFORE REMOVING THE Au/Pt THERMOCOUPLE FROM THE CASE

4.1 Au/Pt Thermocouple Care

4.1.1 Keeping the Fused Quartz Sheath Clean

The fused quartz sheath will gradually devitrify at very high temperatures (usually above 1000°C). Any contamination on the fused quartz will expedite the devitrification process and the devitrification might happen at much lower temperatures (as low as about 600°C). Therefore, keep the fused quartz sheath surface clean. The fused quartz sheath should never be handled with bare hands. Clean cotton gloves or other suitable methods should be used in handling the sheath. A good practice is to wipe the sheath with clean tissue wetted by 200 proof ethyl alcohol or other suitable solvent before exposure to high temperatures. Correct handling of the standard gold/platinum thermocouple will prolong its life expectancy.

4.1.2 Avoiding Over-Heating

Never expose a standard gold/platinum thermocouple to temperatures above 1000°C. The melting point of pure gold is 1064.18°C. The pure gold becomes extremely soft at temperatures close to the melting point.

4.2 Devitrification of Quartz

Devitrification is a natural process with fused quartz materials. The fused quartz is utilized in a glass state. The most stable state for quartz is crystalline. Therefore, devitrification is the tendency of the quartz to return to its most stable state. If the quartz is kept extremely clean and free of contamination, devitrification will occur only at high temperatures. The process occurs more rapidly and at lower temperatures when the glass has become contaminated by alkaline metals (Na, K, Mg, and Ca). The alkalis found in normal tap water can cause the process to start. There is conflicting opinion among the experts as to whether the process can be stopped. Some say that once the process starts it does not stop. Others indicate that once the alkali is removed, the process will stop.

Removal of the devitrification is not practical as it requires drastic measures and is potentially dangerous to the instrument and/or the user.

Devitrification starts with a dulling or opacity of the fused quartz and develops into a rough and crumbling surface. Devitrification ultimately weakens the glass/quartz until it breaks or is otherwise no longer useful.

The best cure for contamination and devitrification is prevention. Being aware of the causes and signs of contamination can help the user take the steps necessary to control contamination of the Au/Pt TC. Keep your Au/Pt TC clean and avoid contact with metals at temperatures above 600°C.

5 Operation

5.1 General

For best results, be familiar with the operation of all heat sources and the read-out instrument. Be sure to follow the manufacturer's instructions for the read-out instrument and the heat sources.

5.2 EMF-Measuring Instruments

The choice of a specific instrument to use for measuring the thermocouple emf will depend on the accuracy required for the measurement. The uncertainty caused from EMF-measurement is often the main component of the total expanded uncertainty when you use a standard Au/Pt thermocouple. As an example, we calculate the measurement uncertainties of the EMF and the corresponding temperature uncertainties caused by using a Model 2182 nanovoltmeter. The 90-day accuracy of the Model 2182 for the range of 100 mV is 25 ppm of the reading plus 3 ppm of the full range. The calculated uncertainties at different temperatures are listed in Table 1.

Table 1 *An example of EMF measuring uncertainties by using Model 2182 nanovoltmeter*

Temperature (°C)	EMF (mV)	dt/dE (mV/°C)	Uncertainty (mV)	Uncertainty (°C)
100	777.90	9.35	0.32	0.034
200	1845.08	11.89	0.35	0.029
300	3141.77	13.98	0.38	0.027
400	4633.43	15.82	0.42	0.026
500	6300.95	17.52	0.46	0.026
600	8135.10	19.16	0.50	0.026
700	10132.25	20.78	0.55	0.027
800	12290.89	22.39	0.61	0.027
900	14609.31	23.98	0.67	0.028
1000	17085.31	25.54	0.73	0.028

5.3 Immersion Requirements

Stem effect can cause measurement errors for any thermometer not immersed in the heat source to an adequate depth. This error is due to heat lost or gained by the sensing element through the thermometer stem. In addition, heat losses occur due to radiation losses from the measuring junction to the housing. The sandblasted finish on the quartz sheath is designed to depreciate losses due to radiation piping.

In order to avoid the conduction error along the stem, the immersion depth should not be less than 400 mm (16 inches).

5.4 Reference Junction

The reference junction should be maintained at a stable temperature with an accuracy better than 0.01 °C. The ice point is the simplest and most reliable method for the purpose. A Dewar vessel filled with a mixture of crushed distilled ice and distilled water is used as the ice point. Pack crushed ice into a Dewar vessel and then add distilled water at 0°C until it just covers the crushed ice. A minimum of 220 mm (8.7 inches) immersion depth into the mixture of crushed ice and distilled water is required for a 5.5 mm-diameter reference junction sheath. The effects of dissolved mineral impurities usually found in tap water in some areas change the freezing point by as large as –0.03°C, therefore, ice made from distilled water should be used.

6 Calibration

6.1 Computing Calibration Coefficients

The electromotive force (emf) of a practical Au/Pt TC, at a temperature of t, can be calculated exactly according to the following equation:

$$E(t) = E_{NIST}(t) + \Delta E(t) \qquad \text{Equation 1}$$

Where E_{NIST} (t) is a reference function determined by Burns and his colleagues at NIST [1],

$$E_{NIST}(t) = \sum_{i=1}^{9} a_i t^i \qquad \text{Equation 2}$$

Where the coefficients of equation 2 are given in Table 2.

ΔE(t) is a difference function:

$$\Delta E(t) = at + bt^2 + ct^3 \qquad \text{Equation 3}$$

where *a, b*, and *c* are coefficients determined at fixed points, e.g. the freezing points of silver, aluminum, and zinc.

Table 2 *Coefficients for Au/Pt thermocouple reference function for the range 0°C to 1000°C*

a1	6.03619861	a6	4.56927038 x 10-14
a2	1.93672974 x 10-2	a7	-3.93430259 x 10-17
a3	-2.22998614 x 10-5	a8	1.429981590 x 10-20
a4	3.28711859 x 10-8	a9	-2.51672787 x 10-24
a5	-4.24206193 x 10-11		

Table 3 is a brief temperature-electromotive force table from the NIST reference function for the Au/Pt thermocouple. You can find the complete table at the end of the manual.

Table 3 *Values of E and the first derivatives of E with respect to t computed from Equation 2*

t(°C)	E(t) (mV)	dE/dt (mV/°C)
0	0.00	6.036
100	777.90	9.353
200	1845.08	11.894
300	3141.77	13.984
400	4633.43	15.818
500	6300.95	17.518
600	8135.10	19.160
700	10132.25	20.781
800	12290.89	22.389
900	14609.31	23.976
1000	17085.31	25.543

6.2 Calibration Procedure

The gold/platinum thermocouple is capable of much higher levels of accuracy and precision than other types of thermocouples. The calibration technique must minimize sources of error to realize this increased performance. Sources of error that might be considered negligible in the calibration of other thermocouples become significant in the calibration of gold/platinum thermocouples. The calibration is done by the fixed point method and the requirements for equipment and technique are demanding. However, laboratories that calibrate SPRTs (standard platinum resistance thermometers) should have the skills and much of the required equipment. This procedure is intended as a guide only. The operator must be familiar with fixed point cell use and high accuracy, low voltage measurement technique. The instruments and apparatus listed in Table 4 are required.

The calibration procedure consists of five steps as shown below.

1. Normalize the potentiometer

2. Most DVMs, even sensitive DVMs and nanovoltmeters lack sufficient accuracy and must be calibrated at the time of use or characterized at the voltage levels representing the thermocouple output at the fixed point temperatures. In this way, the DVM is used as a transfer device and the accuracy of the measurement is derived from the voltage standard, potentiometer, and DVM stability and sensitivity. This step can be omitted if the potentiometer is used directly to measure the thermocouple output.

3. Prepare an ice bath from distilled or deionized ice and water. Pay particular attention to cleanliness during the preparation. Body oils and salts can easily contaminate the bath and cause a temperature depression of 0.010 to

0.015 °C. For more information on the proper preparation and use of the ice-point bath refer to ASTM E 563-97, “Standard Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature” (Available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428, Phone (610) 832-9500, Fax (610) 832-9555.)

Table 4 *Required Calibration Instruments and Apparatus*

Instrument/Apparatus	Range	Accuracy or Uncertainty
Voltage Reference	1.018 VDC	4 ppm
Potentiometer	0 to 20 mV	1ppm
Digital Voltmeter	0 to 20 mV	NA
Fixed Point Cells	TPW (0.010°C)	±0.0005°C
	Tin (231.928°C)	±0.002°C
	Zinc (419.527°C)	±0.002°C
	Aluminum (660.323°C)	±0.004°C
	Silver (961.78°C)	±0.010°C
Furnaces for Fixed Point Cells	200 to 1000°C	±1.0°C
Annealing Furnace	300 to 1000°C	±5.0°C
Ice Bath	0.000°C	±0.002°C

4. Perform measurements at the fixed points starting with the highest temperature (Silver), and working down to the lowest (TPW). At the silver and aluminum points, the thermocouple should be ramped up and down from 450°C at a rate of approximately 2°C/minute. If equipment is not available to ramp the thermocouple and it must be removed directly to ambient, then it should be annealed at 450°C overnight to remove the resulting strains and lattice vacancies. Also, it is advisable to preheat the thermocouple before insertion into the fixed point cell to minimize thermal loading of the cell as well as to reduce the time required for equilibration. During this step, ensure that the ice bath is satisfactory, enough time has been allowed for both the measuring junction and reference junction to equilibrate, and that the DVM has been properly nulled.

5. Apply data corrections (emf corrections for the DVM and temperature corrections for the fixed point cells) and fit the data to a 2nd or 3rd order deviation function, calculate deviation coefficients, and if desired, print a temperature vs. emf interpolation table. There is software available that simplifies this process. A brief description of the calculations is shown below.

   Step 1: Determine the difference emf. Refer to Table 5.

   Step 2: Using least squares, iteration, or matrix methods, fit the difference data to a 2nd or 3rd order polynomial. This example uses matrix methods

Table 5 Difference EMF

Temperature (°C)	Measured emf (mV)	Reference emf (mV)	Difference emf (mV)
0.01	0.046	0.06	–0.014
231.928	2236.116	2236.184	–0.068
419.527	4945.496	4945.627	–0.131
660.323	9320.239	9320.441	–0.202
961.78	16120.277	16120.495	–0.218

to fit to a 2nd order polynomial. Where t = temperature and Δemf = difference emf.

$$matrix\ t = \begin{bmatrix} t_0 & t_0^2 \\ t_1 & t_1^2 \\ t_2 & t_2^2 \\ t_3 & t_3^2 \\ t_4 & t_4^2 \end{bmatrix} \qquad matrix\ \Delta emf = \begin{bmatrix} \Delta emf_0 \\ \Delta emf_1 \\ \Delta emf_2 \\ \Delta emf_3 \\ \Delta emf_4 \end{bmatrix}$$

$$matrix\ operation = solution = (matrix\ t^T \cdot matrix\ t)^{-1} \cdot matrix\ t^T \cdot matrix\ \Delta emf$$

$$solution = \begin{pmatrix} -3.886965 \cdot 10^{-4} \\ 1.624006 \cdot 10^{-7} \end{pmatrix}$$

$$\Delta c_1 = -3.886965\ E-04 \qquad \Delta c_2 = 1.624006\ E-07$$

Step 3: Δc_1 and Δc_2 are programmed into the readout or combined with c_1 and c_2 from the reference function to create an interpolation table.

7 References

1. G. W. Burns, G. F. Strouse, B. M. Liu, and B. W. Mangum, Gold versus platinum thermocouples: performance data and an ITS-90 based reference function, Temperature and Its Measurement and Control in Science and Industry, Volume 6, p. 531, 1992

2. E. H. McLaren and E. G. Murdock, The Pt/Au Thermocouple, Part 1: Essential Performance, Part ll: Preparatory Heat Treatment, Wire Comparisons and Provisional Scale, National Research Council of Canada Publication NRCC/27703, Ottawa, Canada, 1987

8 Appendix

Table 6 *Gold versus Platinum thermocouple — thermoelectric voltage as a function of temperature (°C)*

					Reference Junctions at 0 °C					
°C	0	1	2	3	4	5	6	7	8	9
					Thermoelectric Voltage in Microvolts					
0	0.00	6.06	12.15	18.28	24.45	30.66	36.91	43.19	49.52	55.88
10	62.28	68.71	75.19	81.70	88.24	94.83	101.45	108.11	114.80	121.53
20	128.30	135.10	141.94	148.82	155.73	162.67	169.66	176.67	183.73	190.82
30	197.94	205.10	212.29	219.52	226.78	234.08	241.42	248.78	256.18	263.62
40	271.09	278.59	286.13	293.70	301.30	308.94	316.61	324.32	332.06	339.83
50	347.63	355.47	363.34	371.24	379.18	387.15	395.15	403.18	411.25	419.34
60	427.47	435.63	443.83	452.05	460.31	468.60	476.92	485.27	493.65	502.06
70	510.51	518.98	527.49	536.03	544.60	553.20	561.82	570.49	579.18	587.90
80	596.65	605.43	614.24	623.08	631.95	640.85	649.79	658.75	667.74	676.76
90	685.81	694.88	703.99	713.13	722.29	731.49	740.71	749.97	759.25	768.56
100	777.90	787.27	796.66	806.09	815.54	825.02	834.53	844.07	853.63	863.23
110	872.85	882.50	892.18	901.88	911.61	921.37	931.16	940.98	950.82	960.69
120	970.58	980.51	990.46	1000.44	1010.44	1020.47	1030.53	1040.62	1050.73	1060.87
130	1071.03	1081.23	1091.44	1101.69	1111.96	1122.26	1132.58	1142.93	1153.30	1163.71
140	1174.13	1184.59	1195.06	1205.57	1216.10	1226.66	1237.24	1247.84	1258.48	1269.13
150	1279.82	1290.53	1301.26	1312.02	1322.80	1333.61	1344.45	1355.30	1366.19	1377.10
160	1388.03	1398.99	1409.97	1420.98	1432.01	1443.07	1454.15	1465.25	1476.38	1487.54
170	1498.71	1509.92	1521.14	1532.39	1543.67	1554.97	1566.29	1577.63	1589.00	1600.40
180	1611.82	1623.26	1634.72	1646.21	1657.72	1669.26	1680.82	1692.40	1704.01	1715.63
190	1727.29	1738.96	1750.66	1762.38	1774.13	1785.89	1797.69	1809.50	1821.34	1833.20
200	1845.08	1856.98	1868.91	1880.86	1892.83	1904.83	1916.85	1928.89	1940.95	1953.04
210	1965.14	1977.27	1989.43	2001.60	2013.80	2026.02	2038.26	2050.52	2062.81	2075.11
220	2087.44	2099.79	2112.17	2124.56	2136.98	2149.42	2161.88	2174.36	2186.86	2199.39
230	2211.93	2224.50	2237.09	2249.70	2262.33	2274.99	2287.66	2300.36	2313.08	2325.82
240	2338.58	2351.36	2364.16	2376.99	2389.83	2402.70	2415.58	2428.49	2441.42	2454.37
250	2467.34	2480.33	2493.34	2506.38	2519.43	2532.50	2545.60	2558.71	2571.85	2585.01
260	2598.18	2611.38	2624.60	2637.84	2651.10	2664.38	2677.68	2691.00	2704.34	2717.70
270	2731.08	2744.48	2757.90	2771.34	2784.81	2798.29	2811.79	2825.31	2838.85	2852.41
280	2865.99	2879.60	2893.22	2906.86	2920.52	2934.20	2947.90	2961.62	2975.36	2989.12
290	3002.90	3016.70	3030.52	3044.36	3058.21	3072.09	3085.99	3099.90	3113.84	3127.80
300	3141.77	3155.76	3169.78	3183.81	3197.86	3211.93	3226.02	3240.13	3254.26	3268.41
310	3282.58	3296.76	3310.97	3325.19	3339.44	3353.70	3367.98	3382.28	3396.60	3410.94
320	3425.30	3439.67	3454.07	3468.48	3482.91	3497.37	3511.84	3526.32	3540.83	3555.36
330	3569.90	3584.47	3599.05	3613.65	3628.27	3642.91	3657.57	3672.24	3686.94	3701.65
340	3716.38	3731.13	3745.90	3760.69	3775.49	3790.31	3805.16	3820.02	3834.90	3849.79

Gold versus Platinum thermocouple table continued

°C	0	1	2	3	4	5	6	7	8	9
	Reference Junctions at 0 °C — Thermoelectric Voltage in Microvolts									
350	3864.71	3879.64	3894.59	3909.56	3924.55	3939.56	3954.58	3969.62	3984.69	3999.76
360	4014.86	4029.98	4045.11	4060.26	4075.43	4090.62	4105.82	4121.05	4136.29	4151.55
370	4166.83	4182.12	4197.44	4212.77	4228.12	4243.48	4258.87	4274.27	4289.69	4305.13
380	4320.59	4336.06	4351.55	4367.06	4382.59	4398.13	4413.70	4429.28	4444.88	4460.49
390	4476.12	4491.78	4507.44	4523.13	4538.83	4554.56	4570.30	4586.05	4601.83	4617.62
400	4633.43	4649.25	4665.10	4680.96	4696.84	4712.74	4728.65	4744.58	4760.53	4776.50
410	4792.48	4808.48	4824.50	4840.54	4856.59	4872.66	4888.75	4904.85	4920.97	4937.11
420	4953.27	4969.45	4985.64	5001.85	5018.07	5034.31	5050.58	5066.85	5083.15	5099.46
430	5115.79	5132.14	5148.50	5164.88	5181.28	5197.69	5214.12	5230.57	5247.04	5263.52
440	5280.02	5296.54	5313.07	5329.63	5346.19	5362.78	5379.38	5396.00	5412.64	5429.29
450	5445.96	5462.65	5479.35	5496.07	5512.81	5529.57	5546.34	5563.13	5579.93	5596.76
460	5613.60	5630.45	5647.33	5664.22	5681.12	5698.05	5714.99	5731.95	5748.92	5765.91
470	5782.92	5799.95	5816.99	5834.05	5851.12	5868.21	5885.32	5902.45	5919.59	5936.75
480	5953.93	5971.12	5988.33	6005.55	6022.80	6040.06	6057.33	6074.63	6091.94	6109.26
490	6126.61	6143.96	6161.34	6178.73	6196.14	6213.57	6231.01	6248.47	6265.95	6283.44
500	6300.95	6318.48	6336.02	6353.58	6371.15	6388.75	6406.36	6423.98	6441.62	6459.28
510	6476.96	6494.65	6512.36	6530.08	6547.83	6565.58	6583.36	6601.15	6618.96	6636.78
520	6654.62	6672.48	6690.35	6708.24	6726.15	6744.07	6762.01	6779.97	6797.94	6815.93
530	6833.94	6851.96	6870.00	6888.05	6906.13	6924.21	6942.32	6960.44	6978.58	6996.73
540	7014.90	7033.09	7051.29	7069.51	7087.75	7106.00	7124.27	7142.55	7160.86	7179.17
550	7197.51	7215.86	7234.23	7252.61	7271.01	7289.43	7307.86	7326.31	7344.78	7363.26
560	7381.76	7400.27	7418.80	7437.35	7455.91	7474.49	7493.09	7511.70	7530.33	7548.98
570	7567.64	7586.32	7605.02	7623.73	7642.45	7661.20	7679.96	7698.73	7717.53	7736.34
580	7755.16	7774.00	7792.86	7811.74	7830.63	7849.53	7868.46	7887.40	7906.35	7925.33
590	7944.31	7963.32	7982.34	8001.38	8020.43	8039.50	8058.59	8077.69	8096.81	8115.95
600	8135.10	8154.27	8173.45	8192.65	8211.87	8231.10	8250.35	8269.61	8288.90	8308.19
610	8327.51	8346.84	8366.19	8385.55	8404.93	8424.32	8443.74	8463.16	8482.61	8502.07
620	8521.55	8541.04	8560.55	8580.07	8599.62	8619.17	8638.75	8658.34	8677.95	8697.57
630	8717.21	8736.87	8756.54	8776.23	8795.93	8815.65	8835.39	8855.14	8874.91	8894.69
640	8914.50	8934.31	8954.15	8974.00	8993.87	9013.75	9033.65	9053.56	9073.49	9093.44
650	9113.41	9133.39	9153.38	9173.40	9193.42	9213.47	9233.53	9253.61	9273.70	9293.81
660	9313.94	9334.08	9354.24	9374.41	9394.60	9414.81	9435.03	9455.27	9475.53	9495.80
670	9516.09	9536.39	9556.71	9577.05	9597.40	9617.77	9638.16	9658.56	9678.97	9699.41
680	9719.86	9740.32	9760.81	9781.30	9801.82	9822.35	9842.90	9863.46	9884.04	9904.63
690	9925.24	9945.87	9966.52	9987.18	10007.85	10028.54	10049.25	10069.98	10090.72	10111.48

Gold versus Platinum thermocouple table continued

Reference Junctions at 0 °C										
°C	0	1	2	3	4	5	6	7	8	9
Thermoelectric Voltage in Microvolts										
700	10132.25	10153.04	10173.84	10194.66	10215.50	10236.36	10257.23	10278.11	10299.01	10319.93
710	10340.87	10361.82	10382.79	10403.77	10424.77	10445.78	10466.81	10487.86	10508.93	10530.01
720	10551.10	10572.21	10593.34	10614.49	10635.65	10656.82	10678.02	10699.22	10720.45	10741.69
730	10762.95	10784.22	10805.51	10826.82	10848.14	10869.47	10890.83	10912.20	10933.58	10954.99
740	10976.40	10997.84	11019.29	11040.76	11062.24	11083.74	11105.25	11126.78	11148.33	11169.89
750	11191.47	11213.07	11234.68	11256.31	11277.95	11299.61	11321.28	11342.98	11364.68	11386.41
760	11408.15	11429.90	11451.67	11473.46	11495.27	11517.09	11538.92	11560.78	11582.64	11604.53
770	11626.43	11648.34	11670.28	11692.23	11714.19	11736.17	11758.17	11780.18	11802.21	11824.25
780	11846.31	11868.39	11890.48	11912.59	11934.72	11956.86	11979.02	12001.19	12023.38	12045.58
790	12067.80	12090.04	12112.29	12134.56	12156.85	12179.15	12201.46	12223.80	12246.15	12268.51
800	12290.89	12313.29	12335.70	12358.13	12380.58	12403.04	12425.51	12448.01	12470.52	12493.04
810	12515.58	12538.14	12560.71	12583.30	12605.90	12628.52	12651.16	12673.81	12696.48	12719.16
820	12741.86	12764.58	12787.31	12810.06	12832.82	12855.60	12878.40	12901.21	12924.04	12946.88
830	12969.74	12992.62	13015.51	13038.42	13061.34	13084.28	13107.23	13130.20	13153.19	13176.19
840	13199.21	13222.25	13245.30	13268.36	13291.44	13314.54	13337.66	13360.79	13383.93	13407.09
850	13430.27	13453.46	13476.67	13499.90	13523.14	13546.39	13569.67	13592.96	13616.26	13639.58
860	13662.91	13686.27	13709.63	13733.02	13756.42	13779.83	13803.26	13826.71	13850.17	13873.65
870	13897.14	13920.65	13944.18	13967.72	13991.28	14014.85	14038.44	14062.05	14085.67	14109.30
880	14132.96	14156.62	14180.31	14204.01	14227.72	14251.45	14275.20	14298.96	14322.74	14346.54
890	14370.35	14394.17	14418.01	14441.87	14465.74	14489.63	14513.54	14537.46	14561.39	14585.35
900	14609.31	14633.30	14657.30	14681.31	14705.34	14729.39	14753.45	14777.53	14801.62	14825.73
910	14849.86	14874.00	14898.15	14922.32	14946.51	14970.72	14994.94	15019.17	15043.42	15067.69
920	15091.97	15116.27	15140.58	15164.91	15189.26	15213.62	15237.99	15262.38	15286.79	15311.22
930	15335.66	15360.11	15384.58	15409.07	15433.57	15458.09	15482.62	15507.17	15531.73	15556.31
940	15580.91	15605.52	15630.15	15654.79	15679.45	15704.12	15728.81	15753.52	15778.24	15802.98
950	15827.73	15852.50	15877.28	15902.08	15926.90	15951.73	15976.57	16001.44	16026.31	16051.21
960	16076.12	16101.04	16125.98	16150.94	16175.91	16200.90	16225.90	16250.92	16275.95	16301.00
970	16326.07	16351.15	16376.25	16401.36	16426.49	16451.63	16476.79	16501.97	16527.16	16552.36
980	16577.59	16602.82	16628.08	16653.35	16678.63	16703.93	16729.25	16754.58	16779.92	16805.29
990	16830.67	16856.06	16881.47	16906.90	16932.34	16957.79	16983.26	17008.75	17034.26	17059.78
1000	17085.31	17110.86	17136.43	17162.01	17187.61	17213.22	17238.85	17264.49	17290.15	17315.83